Towards Low Technology - Higher Performance Architecture: Potentials of Alternative Construction in West Scotland

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Considering current problems in matters of sustainability that holistically affect economic, social, political and environmental concerns, numerous reasons suggest a change of mindset in design and construction approaches to be beneficial and necessary in order to tackle building impact. The construction industry is highly correlated to the emergence and sustainment of these problems; over 50% of the planets' resources are transformed into construction materials and building operation alone is responsible for 42% of the final energy consumption and 35% of all green house gas emissions in the EU. Furthermore, the construction industry is one of the biggest contributors to the provision of employment and a stable economy. With this overall impact on environment and human lives, the sector is largely accountable to the reduction biodiversity and causing environmental deprivation, however, as such it also has great potential to contribute to long-term sustainability.

The notion of Low Technology in architecture provides a holistic response to all this problems. It is based on the principles of simple function, ease of manufacture, ease of use, robustness and ease of maintenance. The concept has a history of at least 3000 years, during which knowledge of nature and climate has been passed on from generation to generation ensuring building suitability to site, local weather conditions, long lifecycles and good levels of comfort. In contrast to the popular notion of High Tech, which relies on a strategy of compensation aiming to balance out inner climate conditions with intelligent building technology, Low Tech interacts directly with site and climate in order to minimise energy demand by taking advantage of material properties combining these with architectural and constructive measures.

A direct dialog between indoor and outdoor climate is achieved by using simple but strategic design and regionally available natural materials such as earth, straw or hemp.

The question of locality as a response to the mitigation of global warming has been prevailing since the 1992 UN Conference on Environment and Development and the presentation of the Agenda 21, which states that the solutions to global problems are individually tailored local approaches. For developed countries, which use disproportional amounts of resources to their population size, this requires a major swift towards energy conservation in building design. However, the whole extent of the industry also plays an important part within this process starting with the utilisation of local, indigenous and benign materials. In Scotland, due to the climate with a yearly average relative humidity of 82%[1] and strong winds, the use of regional materials is challenging on all levels – from extraction to construction. However, a growing industry-wide interest suggests potential of alternatives to common materials as it is realised that technology cannot provide the ultimate solution to a problem it has caused.

In order to test the potentials of natural materials in the climate of west Scotland, a building site in Glasgow (Figure 1) was chosen as a basis for examination of performance, strategic building orientation and overall suitability of natural materials in a residential context. It is estimated that approximately a quarter of the total building total stock will be new build by 2050.

Figure 1. Project Site

To date, the residential sector is responsible for a yearly amount of 25 to 27% of the total economy carbon emissions and deep emission cuts are hence an imperative if the government set targets of 80% emission reduction by 2050 as well as the 2016 zero carbon policy for new build homes are to be achieved.

The current poor performance of buildings throughout the U.K. however, are limiting new property carbon emissions allowances to a minimum[2] while stricter regulations make building increasingly unaffordable - potentially kindling a housing crisis and inherent social problems[3].

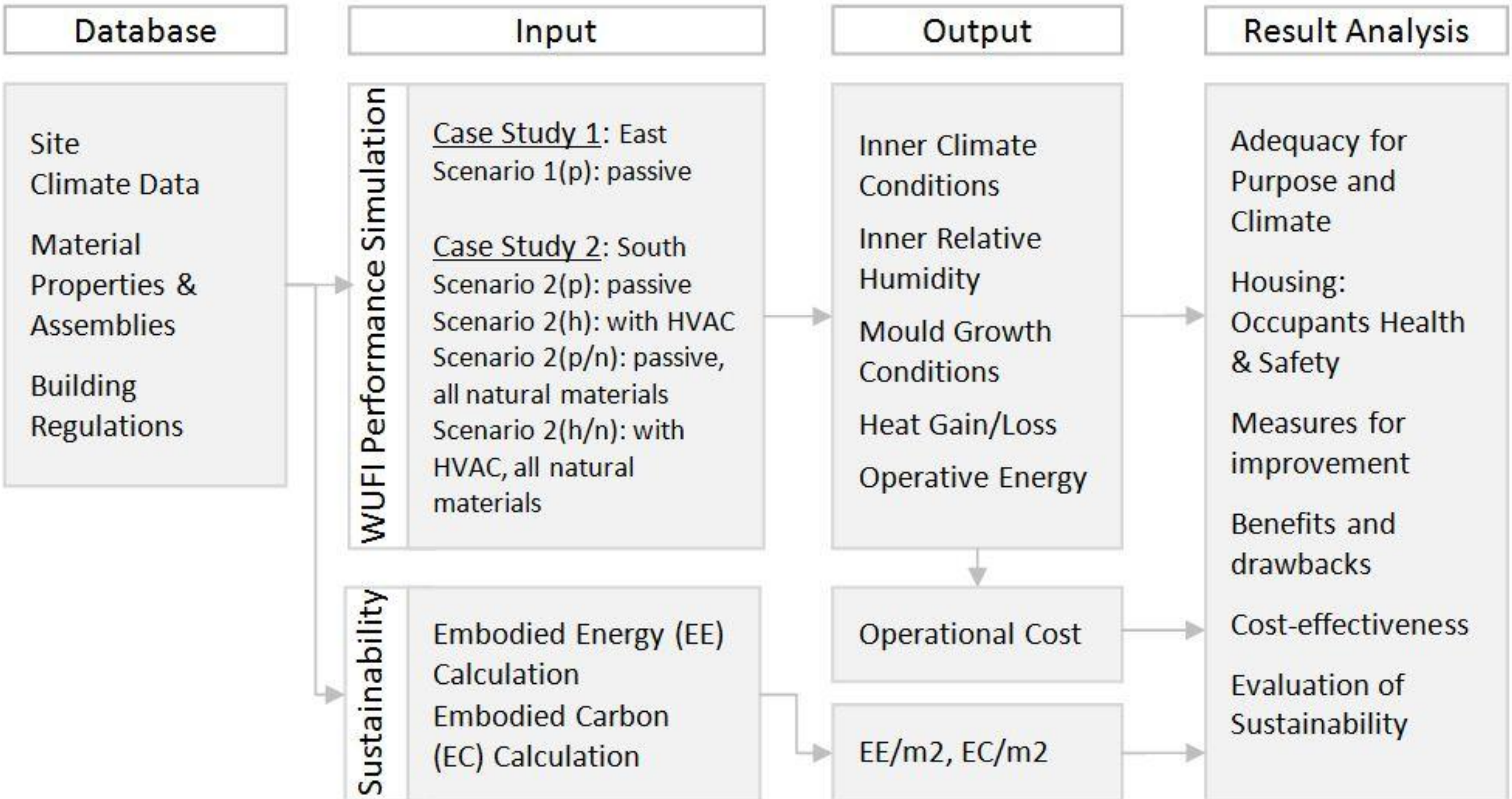

Figure 2. Project Structure

Accordingly, housing urgently requires innovation, thus a building model of semi-detached house was developed for research purposes. The building complies with current Scottish Building Regulations and was tested in a whole-building computer simulation using WUFI software for hygrothermal building modelling. The program ensures realistic results as it is validated through laboratory as well as field testing by the renowned Fraunhofer Institute of Building Physics. It includes output of inner temperatures, inner relative humidity, mould growth conditions, heat gain and loss as well as operational energy requirements for achieving a set comfort profile. Accordingly, building performance was investigated in passive scenarios as well as including HVAC and operational cost effectiveness. Environmental sustainability was evaluated via a calculation of embodied energy and embodied carbon.

Six natural materials categorised in thermal mass (Rammed Earth and Cob), insulation (Straw Bale and Hemp-Lime) and hybrid construction (Light Clay and Adobe Hybrid), were tested against a Timber Frame Base Case in two case studies with east and south main facade orientation (Figure 2). Timber frame is currently the most popular construction method in Scottish new housing with 67.8%[1] despite the country's comparatively low account of woodland – 19% compared to EU average of 42%[4] - thus rendering ecological aspects of timber construction rather moot.

However, research findings highlighted an overall good performance of materials and the Low Tech approach and thus adequacy of alternative materials to the Scottish climate.

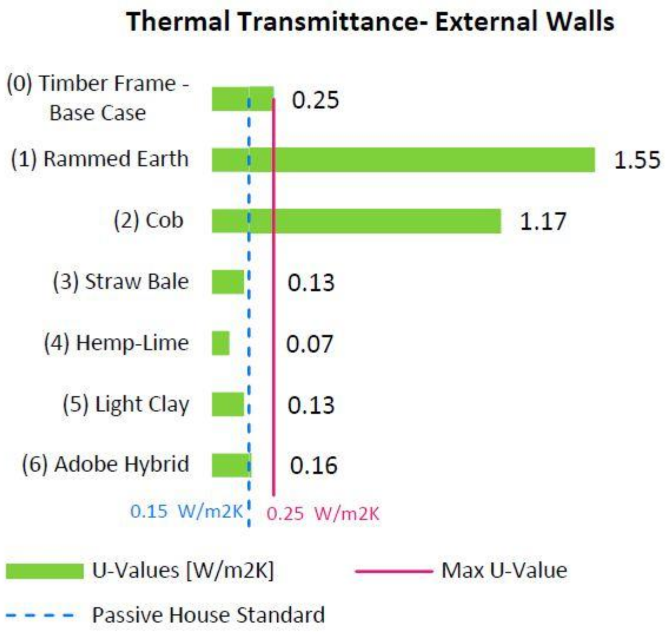

Figure 3. Thermal Transmittance (U-Value)

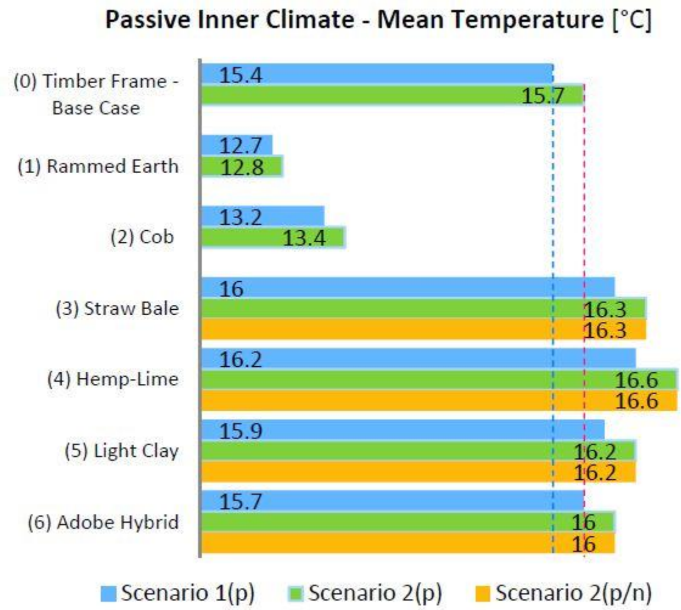

Figure 4. Passive Inner Climate

U-values of the case-dependent wall assemblies directly indicating their thermal properties (Figure 3). The Timber Frame Base Case marks the current standard set by the 2011 Scottish building regulations at 0.25 W/m²K. The simulation showed that bare thermal mass assemblies consisting of solely Rammed Earth or Cob are unable to perform to current requirements, however, the insulation and hybrid construction Straw Bale, Hemp-Lime, Light-Clay and Adobe Hybrid not only over-perform but also achieve the much stricter Passivhaus requirements for thermal transmittance of 0.15 W/m²K.

On this basis, the influence of strategic building orientation was examined. In order to do so, all material scenarios had to be investigated for achievable passive conditions – excluding HVAC. The whole-building simulation attained overall higher mean temperatures, lower relative humidity and fewer heat loss with a south facing main facade as opposed to an east facing front. Accordingly, the essential challenge to test the potentials of solar gains in Glasgow's rainy climate has exposed the existence of potentials to be expanded upon.

However, the simulation further showed that a building constructed entirely from natural materials would not significantly benefit from the heat storage capacity of internal building elements such as floors and separating walls (Figure 4). A hybrid construction of common building elements and external walls from Straw Bale, Hemp-Lime or Light Clay achieves the highest inner temperature.

However, compared to industrial materials, all natural materials majorly benefit from their moisture regulative and natural desiccation properties, which is especially important for humid climates. According to findings of the Fraunhofer Institute of Building Physics the ideal relative humidity in enclosed spaces is between 30 and 70%. The maintenance of the ideal humidity is not only important for material performance but moreover for occupant's health and comfort. Hydration of the building material can impair insulative properties and lead to irreversible damage to occupants' health caused by mould growth.

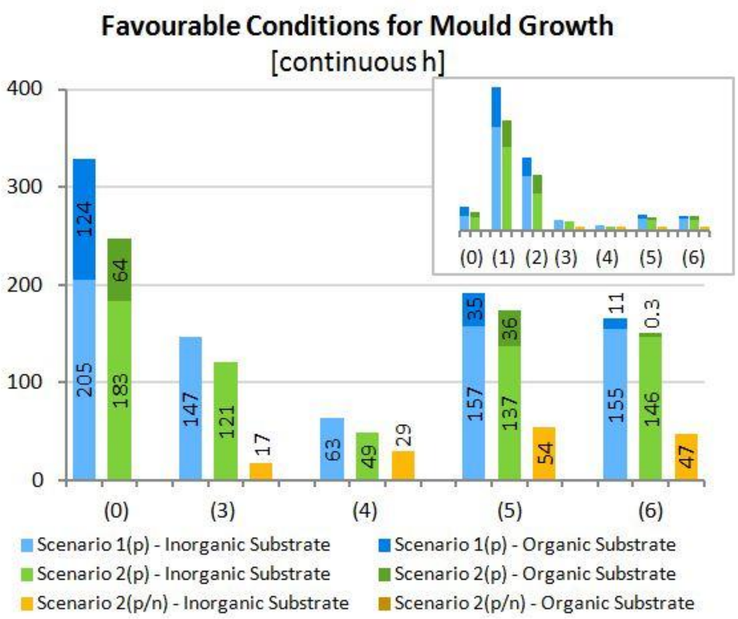

Figure 5. Favourable Conditions for Mould Growth

There is generally accepted connection between poor housing and ill health; however, studies conducted in Glasgow[6] show that the highest risk to health in housing is attached to cold, damp and mouldy conditions suggesting a direct link between cold and excess mortality rates. Typically, there are 20,000 more deaths recorded between January and March than average U.K. yearly rates, which is correlated to respiratory conditions as a main cause and found two to three times more likely to occur with patients living in damp homes. Furthermore, dampness within or around building elements influences their thermal performance due to conductivity changes and can cause damage to the construction via mechanical forces such as contraction, expansion or stress. However, the research findings for a passive building showed that the insulation models Straw Bale and Hemp-Lime perform best and keep inner relative humidity to around 65%; the Base Case however, with results around 70%, would require dehumidification to safeguard from moisture induced damage. Figure 5 further details the invaluable moisture regulative properties of natural materials.

The holistic building performance simulation in WUFI calculates typical hygrothermal effects - such as moisture sources and sinks inside a room and moisture input from the envelope – thus exposing mould growth potential with a building.

Accordingly, the total risk of fungal growth is significantly higher in the mixed construction building models than in the buildings, which are exclusively built from natural materials. The indication that mould is more likely to develop within the inorganic substrate might seem unorthodox however, is explicable considering Glasgow's extremely humid climate and the fact that most materials are capable of sustaining mould growth if the conditions for desiccation do not exist. A constant combination of substrate, nutrients such as debris from dust and skin-cells, and humidity will develop fungi between 24 hours and 10 days of the provision of the growing conditions[7]. Accordingly, Figure 5 shows the continuous hours of mould growth allows an accurate conclusion of mould growth risk within the different constructions. The graph reveals that the buildings from predominantly natural materials are at the lowest risk of developing fungi due to their moisture regulating properties that make substrates unsuitable for mould thus ensuring lasting prevention. Common materials often use biocides, which work for limited time only and often cause allergic reactions and other health issues. Reasonably, adding reactive Ventilation and Air Conditioning systems (HVAC) that balances out harmful climate preconditions eliminates mould growth potential. The system keeps relative humidity to an ideal of 52 to 55% indifferent of the construction however with highly varying requirements of operative energy and therefore cost.

A calculation of energy cost from energy requirements according to WUFI directly compares cost effectiveness of alternatives to the majority of current Scottish construction in timber frame. The average energy consumption for space heating in U.K. dwellings built after 2000 is about 140 kWh per square metre per year (kWh/m²a) according to BRE estimates. The continuous tightening of building regulations over the years however, show their positive effect in the Base Case (0), which only minimally surpasses the EU definition of Low Energy Buildings that is a use of 40 to 60 kWh/m²a for space heating. Straw Bale, Hemp-Lime and Light Clay however match the requirements in all scenarios (Figure 6). However, to put energy efficiency in monetary terms, it was assumed that all energy demand is covered by standard electricity at a rate of £0.1125 per kWh excluding annual fixed cost. Hemp- Lime (Case 4) is the most cost-effective with monthly costs of £54.43 (£653.16 a year) for a 88.5 m² house. Operational cost of Light Clay (5), Straw- Bale (3) and Adobe Hybrid (6) are lower than the Base Case (0) running cost of £61.56 a month, however compared to the heating cost of Cob and thus the existing U.K. housing stock, all afore mentioned cases are approximately twice as energy and cost effective (Figure 7).

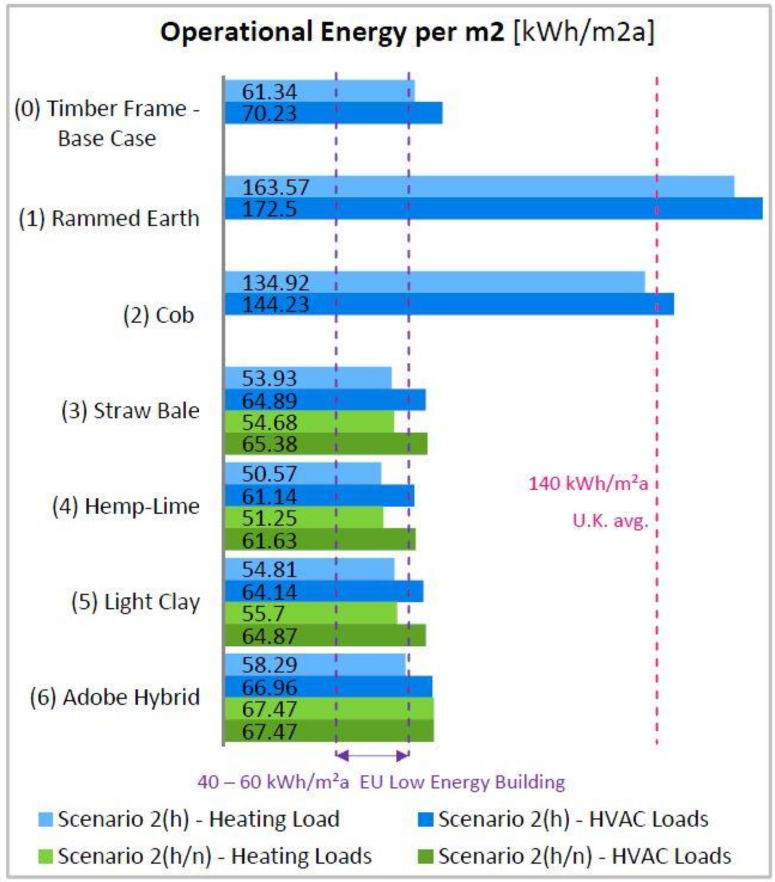

Figure 6. Operational Energy per square metre

Operational Cost					
	Case	Per Annum [£]		Per Month [£]	
		Heating	HVAC	Heating	HVAC
Timber Frame	2.0(h)	650.35	738.76	54.2	61.56
Rammed Earth	2.1(h)	1667.65	1756.56	138.97	146.38
Cob	2.2(h)	1382.58	1475.23	115.21	122.94
Straw Bale	2.3(h)	576.61	685.61	48.05	57.13
	2.3(h/n)	584.05	690.50	48.67	57.54
Hemp-Lime	2.4(h)	543.09	648.31	45.26	54.03
	2.4(h/n)	549.88	653.16	45.82	54.43
Light Clay	2.5(h)	585.37	678.19	48.78	56.52
	2.5(h/n)	594.21	685.43	49.52	57.12
Adobe Hybrid	2.6(h)	706.21	619.92	51.66	58.85
	2.6(h/n)	711.30	711.30	59.28	59.28

Figure 7. Operational Cost

Finally, regional appropriateness of alternative materials is a question of environmental sustainability. It has to be pointed out that this is a particularly ambivalent endeavour that will probably never be fully convertible and comparable in numbers. However, for research purposes, a calculation of Embodied Energy (EE) and Embodied Carbon (EC) per square meter was undertaken.

Transport to site can often make a significant contribution the overall EE and EC values, therefore a close comparison especially within a regional context is important. Available data[8] for EE and EC gives numbers for energy use from material extraction to factory gate ('cradle to gate'). Accordingly, the average distance to site was included to the cradle-to-gate results by adding energy use data of 2.19 MJ per km and carbon emissions of 1.12 kgCO2 per km[9]. Due to lorry capacity, limits on transportation are either imposed by maximum weight or volume, resulting in U.K. average hauling distances of 242.6 miles (390.42 km) by volume and 106.8 miles (171.9 km) by weight.

There is an ambiguity within the topic of local materials and transport. The U.S. green building certification system LEED for example, defines material sourcing within a radius of 500 miles (805 km) as local. The paradox within the topic of natural materials however are the high gauges of around 500 mm necessary for basic assembly, but shorter average transportation distance for high density materials, which is clearly derived from industrial practice. Despite the fact that subjecting earth for instance, to a 172 km drive to site sounds absurd, assembly width alone would suggest that reasoning according to common practice is questionable in this case. It is generally possible to source materials locally from farms or the site itself as many completed Low Tech projects have shown.

Accordingly, both, the application of haulage as well as disregarding transport emissions have a rationale in a discussion on alternative construction - the former for consideration of large-scale developments, which might include prefabricated components, and the latter for one-off projects and self-build.

In terms of sustainability however, the thermal mass models Rammed Earth and Cob, which proved unfit for purpose and climate, are among the most sustainable. Including transport, Cob has the lowest EE in all scenarios. Despite their 500 mm thick walls, this suggests that further investigations and development of the material has grounds for adaptation of material to fit the Scottish climate.

However, excluding transport and despite its thick walls, the Straw Bale model has the overall lowest EE per m² in all Scenarios. In comparison, the Timber Frame Base Case has an EE of approximately 720 MJ/m² higher than the Straw Bale construction although its walls measure only 200 mm compared to 340 mm in Straw Bale.

Generally, the research found evidence supporting an alternative to industrial construction methods without compromising comfort standards. The hygrothermal computer simulation in WUFI gave the overall best results for the insulation models Hemp-Lime and Straw Bale, followed by the hybrid models Light Clay and Adobe Hybrid, which combine insulation and thermal mass. Despite their basic assembly, these cases performed comparably to the Timber Frame Base Case, thus to current building regulations, and at times even to Passivhaus standard.

Growing interest in these alternatives motivated by the realisation that building efficiency targets are increasingly difficult to reach with industrial construction methods in an economy- driven world, suggests that the market demand will be rapidly growing as well. However, current developments further indicate that the implementation of local materials and construction methods are necessary for construction to move towards a circular economy[10], which is based on a transformation of the familiar linear model – 'take, make, dispose' – into a cyclical model. Construction has to focus on using goods more intensively and materials to their full potential, extending life-cycles and designing for eventual dismantling in order to achieve government aims such as Scotland's Zero Waste Plan.

In summary, natural material construction benefits from a high sustainable and thermal performance while being potentially cheaper than industrial construction. Drawbacks are currently resulting from a lack of research especially in Scotland, local suppliers and experienced planners and labour force. This creates major hurdles towards a wider acceptance as the U.K. construction industry is rather generally suspicious towards innovation and will most likely only be persuaded by an economic argument.

However, it is only logical that prevailing technological solutions in material resourcing, production and building operation cannot provide sustainable, long-term solutions and while it has to be highlighted that the performance of the best cases is not significantly better than Base Case results, they proved to be at the least comparable despite their simple assembly while surpassing in environmental, economic and health concerns. In order to ensure continuing survival on the planet society must strive to become more sustainable as a whole. As such, sustainability has to be addressed in a holistic manner considering every aspect of human lives. Accordingly, Low Tech provides many basic answers to today's conundrums.

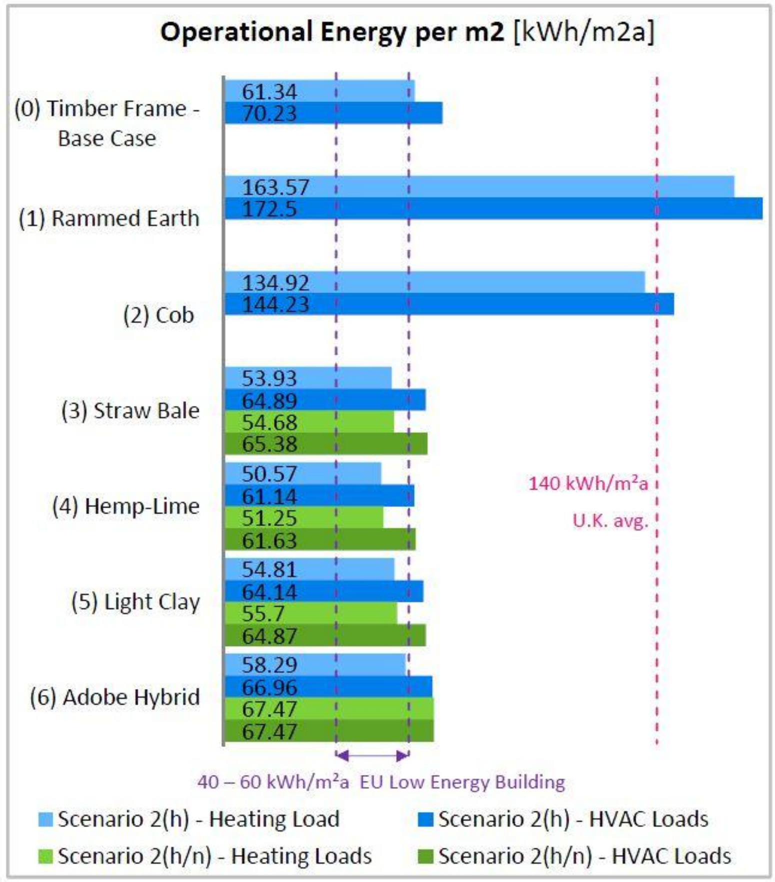

Figure 8. Embodied Energy and Embodied Carbon per Square metre

[1] www.meteonorm.com
[2] Boardman 2007. *Home Truths: A Low-Carbon Strategy to Reduce UK Housing Emissions by 80%by 2050.* Oxford: University of Oxford's Environmental Change Institute.
[3] Barker 2004. *Delivering Stability: Securing our Future Housing Needs. Review of Housing Supply.Final Report-Recommendations.* London: Crown.
[4] UK Timber Frame Association: www.uktfa.com
[5] EuroStat 2010. *Environmental statistics and accounts in Europe: 2010 edition*. Luxembourg: Publications Office of the European Union.
[6] Wilkinson 1999. *Poor Housing and Ill Health – A Summary of Research Evidence*. The Scottish Office Central Research Unit
[7] Sedlbauer 2001. *Vorhersage von Schimmelpilzbildung auf und in Bauteilen.* Thesis (PhD). Lehrstuhl für Bauphysik, Universität Stuttgart.
[8] Hammond and Jones 2008. *Inventory of Carbon and Energy (ICE).* University of Bath.
[9] Vanek and Campbell 1999. UK road freight energy use by product: trends and analysis from 1985 to 1995. *Transport Policy*. Volume 6, Issue 1, p 236-246.
[10] The work will be presented at the conference "The Circular Economy: New Opportunities for Design and Construction in Scotland" to be held at the University of Strathclyde on the 1st June 2012. For information see pages 22-23 of this issue of Innovation Review.